Hyperspectral Remote Sensing Of The Coastal Ocean: Adaptive Sampling And Forecasting Of Nearshore In Situ Optical Properties

W. Paul Bissett

Florida Environmental Research Institute
4807 Bayshore Boulevard, Suite 101
Tampa, FL 33611
phone: (813) 837-3374 fax: (813) 902-9758 email: pbissett@flenvironmental.org
Award # N000149910198

LONG-TERM GOAL

We propose to develop and validate an integrated adaptive sampling and modeling system for nowcasting and forecasting the 3-dimensional inherent optical properties (IOPs) off of the New Jersey coast. This will be accomplished by developing an integrated observation network that will provide real-time data to allow for adaptive sampling in near-shore coastal waters. This data will also be used to develop hyperspectral remote sensing techniques for optically complex coastal waters. In addition, it will be used to provide the physical, chemical, biological, and optical data necessary to develop coupled data assimilative hydrodynamic ecosystem models.

OBJECTIVES

This project is part of a larger ONR effort at the Rutgers University Long-term Ecosystem Observatory [LEO-15] to collect, model, assimilate, and simulate high resolution 3-D physical, biological, chemical, and optical data [see Schofield ONR Award# N000149910196 for an overall program description]. Our objectives in this award are to collect, analyze, assimilate, and simulate hyperspectral inherent and apparent optical properties [IOPs and AOPs] at LEO-15. In particular, we wish to build upon an existing oceanic version of a predictive ecological simulation (EcoSim 1.0) to develop the tools, techniques, and code to transform this model into a data assimilative, prognostic coastal ocean model of IOPs and AOPs.

APPROACH

The short-term prediction of the inherent and apparent optical properties requires accurate prediction of the physical, chemical, biological, and optical interactions of the oceanic environment. Such an undertaking is an imposing feat, and requires far more than a single investigator could hope to accomplish. However, this goal provides the background against which our efforts are measured. Working within a larger framework of experimentalists and physical numerical modelers, we are collecting and analyzing hyperspectral data, both in situ and from remote-sensing platforms, and modifying ecological code to develop the data assimilation techniques necessary for prognostic optical simulations.

The data are collected as part of the Coastal Predictive Skill Experiments [CPSE] each summer at the LEO-15, offshore of Tuckerton, NJ. The CPSE represented a multi-institution effort funded by ONR through the Hyperspectral Coupled Ocean Dynamic Experiment [HyCODE], the Coastal Ocean

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 1999**	2. REPORT TYPE	3. DATES COVERED **00-00-1999 to 00-00-1999**

4. TITLE AND SUBTITLE **Hyperspectral Remote Sensing Of The Coastal Ocean: Adaptive Sampling And Forecasting Of Nearshore In Situ Optical Properties**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Florida Environmental Research Institute,4807 Bayshore Boulevard, Suite 101,Tampa,FL,33611**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

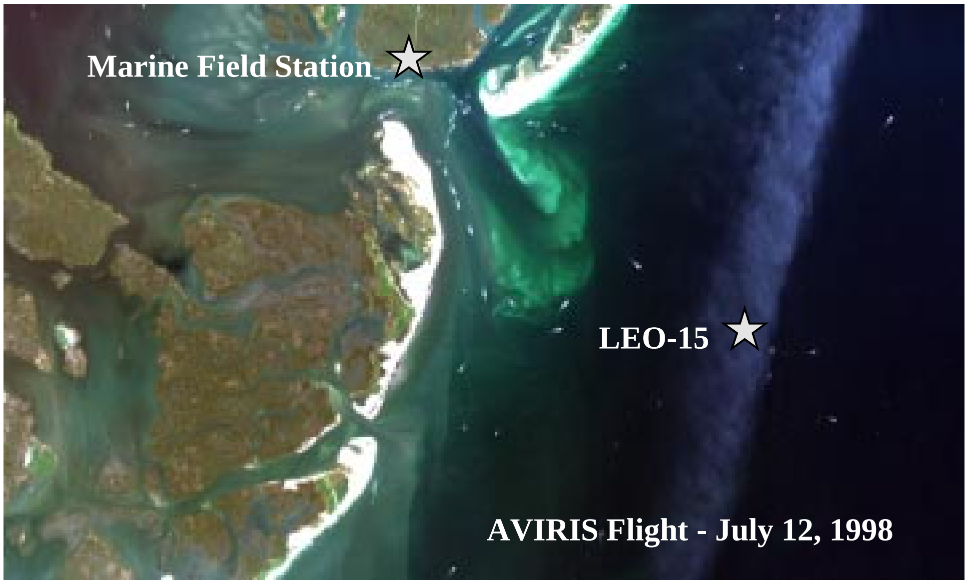
14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Modeling and Observation Program [COMOP], and the two awards from the National Ocean Partnership Program. Figure 1 shows a pseudo-RGB image of the LEO-15 site created from an AVIRIS in July of 1998.

Figure 1. AVIRIS Pseudo-RGB Image from LEO-15



Addition hyperspectral data have been collected as part of the ONR COBOP field experiment at Lee Stocking Island [LSI], Bahamas. Our participation in the COBOP experiment focused on data collection and inter-calibration of a new hyperspectral surface water buoy from Satlantic, Inc. [Satlantic H-TSRB], which is to be deployed at the LEO-15 site in July 2000.

Critical to the development of short-term optical forecasting simulations is an accurate initialization and validation data stream. A large fraction of this data stream is to be collected by either hyperspectral imaging spectrometers (mounted on aircraft or satellites) or autonomously mooring hyperspectral radiometers. Upon review of the hyperspectral AVIRIS data from LEO-15, the Ocean PHILLS data from LSI, and the upwelling radiance data from the H-TSRB (0.6 m depth), it became clear that any hyperspectral data assimilation technique would require some means to ground-truth the values of the water-leaving radiance, $L_w(\lambda)$, or remote-sensing reflectance, $R_{rs}(\lambda)$, being collected. Analysis of the image data suggested that there were major difficulties in validating the sea surface, water-leaving radiance values. These difficulties fell mainly into two divisions, instrument calibration and atmospheric correction. While these problems are beyond the scope of this research project, accurate hyperspectral data is critical to the success of our project. Thus, we are trying to provide a means to use the H-TSRB to ground-truth the hyperspectral images, such that those working on instrument calibration and atmospheric correction issues will have accurate data to resolve their issues. We choose to address these issues from a modeling standpoint to further our aims of hyperspectral simulation. This work is being accomplished with Curt Mobley [Sequoia Scientific, Inc.] and the H-TSRB COBOP investigators.

Additionally, as part of the initialization and validation effort, we are addressing the description of particle-specific optical properties with Dariusz Stramski [Scripps Institute of Oceanography], Oscar Schofield [Rutgers University] and Mark Moline [California Polytechnic State University]. In particular, we wish to create a database of particle-specific optical properties as a function of phytoplankton species, nutrient state, light history, temperature, and cell size. These data will be used in EcoSim to produce temporally varying estimates of depth-dependent IOPs. In collaboration with Scott Glenn and Dale Haidvogel [Rutgers University], the completed coastal ocean EcoSim 2.0 will be coupled with the Rutgers University SCRUM model of the physical circulation of the New York Bight.

WORK COMPLETED

The work of the past 9 months has been focused in two areas.

1) Developing the methodology to create a database of particle-specific absorption, scattering, and scattering phase function for multiple groups of phytoplankton as a function of spectral light and nutrient history, temperature, and cell size.
2) The collection of hyperspectral data with the H-TSRB, and modeling the changes in depth-dependent $E_d(\lambda)$ and $L_u(\lambda)$, and surface water $L_w(\lambda)$ and $R_{rs}(\lambda)$ as a function of bathymetry, pigment concentration, solar elevation, wind speed, and bottom type in an attempt to derive a simple relationship between the H-TSRB and the aircraft-collected hyperspectral images.

RESULTS

It is still early in the formulation of the optical database. While the framework is based on previous work [Stramski and Mobley, 1997, Limnology and Oceanography, v42:538-549], the data required to specify the changes in IOP for the various phytoplankton species is being compiled from many different investigators, and across decades of phytoplankton research. These data frequently do not contain the entire suite of particle specific optical properties (hyperspectral absorption, scattering, index of refraction, and scattering phase function) that we would like to have. So new interpolation schemes are being developed to attempt to derive these data from limited data sets. In addition, new experiments are being planned to collect the entire suite of specific optical properties over a range of light and nutrient conditions.

In attempting to develop a simple methodology to validate remotely collected $L_w(\lambda)$ with the H-TSRB, we were hearten by the relationship seen in Figure 1. The surface water reflectance ratio is define as:

$$R(\lambda) = \frac{L_w(\lambda,0^+) / E_d(\lambda,0^+)}{L_u(\lambda,0^-) / E_d(\lambda,0^-)} \qquad (1)$$

This ratio appears to be stable across the visible spectrum in an idealized, deep-water simulation. We thought that with minor modification we could apply this to the shallow water conditions seen around LEO-15 (Figure 1) and LSI. If this ratio is truly stable, and the values for $L_u(\lambda,0^-)$ could be estimated from $L_u(\lambda,0.6)$, then a simple methodology to ground-truth hyperspectral images could be developed. Thus, we define a ratio called, $R_{TSRB}(\lambda)$:

$$R_{TSRB}(\lambda) = \frac{L_w(\lambda,0^+) / E_d(\lambda,0^+)}{L_u(\lambda,0.6) / E_d(\lambda,0.6)} \qquad (2)$$

Figure 2 shows the deep-water results assuming both a 2 m and 5 m slab of well-mixed water, overlying an infinitely deep water column. While there are some differences between the high chlorophyll a, low chlorophyll a, and actual LSI AC-9 data runs, the largest differences are confined to the region greater than 700 nm. As the veracity of aircraft hyperspectral data is marginal at these longer wavelengths, this did not appear to be a major roadblock in our efforts. From these runs it still appeared that the H-TSRB could provide simple, direct validation of the image data in collected in optically shallow waters.

Figure 1. $0^+/0^-$ Reflectance Ratio. Hydrolight 4.02 calculation, Case 1 optical model, constant 0.05 chlorophyll a, 2 meters of water, infinite bottom, 45 degree sun angle, no clouds, 2 m/s wind.

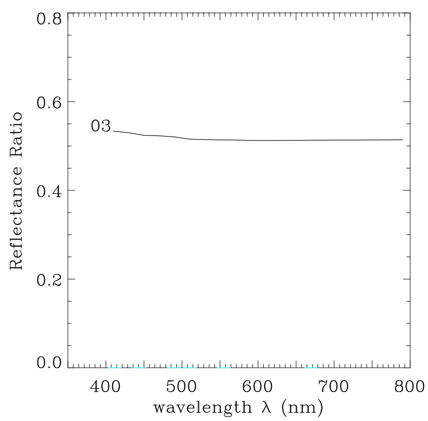


Figure 2(a). 2 meter infinite bottom calculations. Case 1 optical model IOPs with 0.05 and 10.0 chlorophyll a concentrations, as well as AC-9 IOPs from Rainbow garden with 0.05 chlorophyll a (for fluorescence).

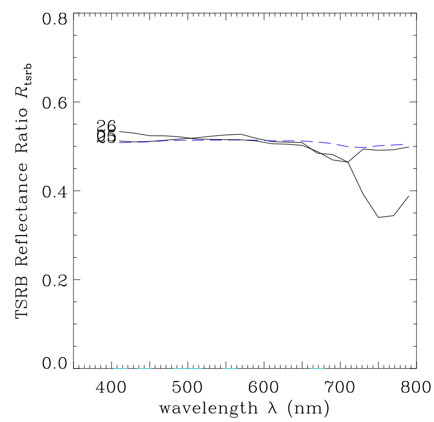


Figure 2(b). 5 meter infinite bottom calculations. Same parameter set as Figure 2(a).

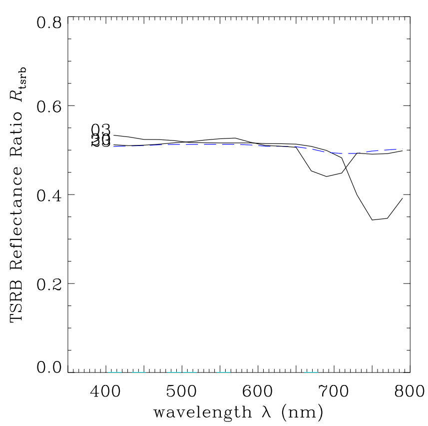
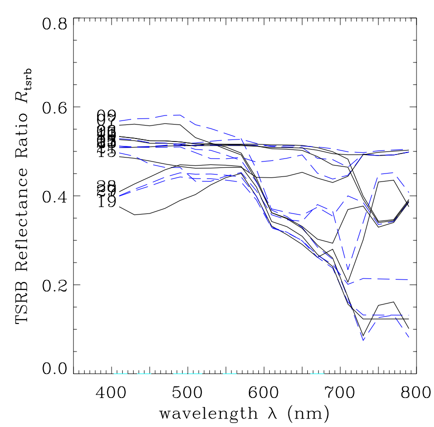


Figure 3. R_{TSRB} under varying depth, bottom types, and IOP conditions.



However, Figure 3 shows a subset of >60 Hydrolight 4.02 runs in shallow water conditions that were accomplished while trying to address this issue. As is evident, the shallow water $R_{TSRB}(\lambda)$ is anything but stable. In addition, there is very little pattern to the variation between the different runs (at least to a 0^{th} or 1^{st} order). These results suggest a simple relationship between surface water reflectance and

$R_{TSRB}(\lambda)$ in optically shallow water may be difficult find, and usage of this data to directly ground-truth hyperspectral aircraft images may be tenuous.

Perhaps a better method of ground-truth would be to create a large database of Hydrolight solutions. Then, one could use look up-tables, neural networks, or optimization schemes to search this database to determine the best fit between the surface water AOPs, and depth-dependent IOPs. By developing a methodology of running multiple IOP scenarios through Hydrolight, including depth-dependent water-column IOPs, eventually a large data space could be created that would cover virtually all possible combinations. While time consuming up front, each run would only have to be accomplished once. Such a data set could then be given to the community as part of an algorithm that calculates bathymetry, bottom type, and depth-dependent IOPs simultaneous. These methods are currently being pursued by Kendall Carder [USF] and Curtiss Davis [NRL].

On the positive side, the deep-water solutions (Figure 2) show promise in providing a relationship between surface water reflectance and the reflectance measured by a tethered buoy. This may provide a means to ground-truth hyperspectral images over optically deep waters. We intend to explore the functionality of this relationship during the HyCODE LEO-15 field experiment in July 2000.

IMPACT/APPLICATIONS

Forecasting the near-shore optical properties requires the correct numerical formulation of the physical, chemical, biological, and optical interactions in the coastal ocean. Once this formulation is accomplished, forecasting requires the ability to assimilate remotely sensed data to constraint the solution to realistic projections. The instrumentation and techniques developed as part of this program are a necessary component of the forecasting process.

RELATED PROJECTS

With support from N000149910197, N000149910196, and N000149810003, Mark Moline [Cal Poly], Oscar Schofield [Rutgers] and Dariuzs Stramski [Scripps] are helping to develop the particle-specific IOP database.

With the support of N000149910196, Scott Glenn and Dale Dale Haidvogel [Rutgers] are developing the 3-D physical forecasting model of the New York Bight that will be coupled to the EcoSim 2.0 code.

With support from N0001497C0018 and N0001499C0019, Curt Mobley [Sequoia] is helping to develop techniques to utilize the H-TSRB data, as well as to develop an optimal radiative transfer code to be used in conjunction with a 3-D ecological simulation.

PUBLICATIONS

Schofield, O., J. Grzymski, W. P. Bissett, G. Kirkpatrick, D. F. Millie, M. Moline and C. S. Roesler (1999). “Optical monitoring and forecasting systems for harmful algal blooms: possibility or pipe dream?” Journal of Phycology: (in press).